3G Wireless Systems

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Course Presenter's Biography

Erik Dahlman received the Master of Science degree and Doctor of Technology degree from the Royal Institute of Technology, Stockholm in 1987 and 1992 respectively. He is currently the Senior Expert in Radio Access Technologies within Ericsson Research.

Erik Dahlman was deeply involved in the development and standardization of 3G radio access technologies, first in Japan and later within the global 3GPP standardization body. More recently he has been involved in the standardization/development of the 3GPP Long Term Evolution (LTE) and its further evolution into LTE-Advanced. He is currently part of the Ericsson Research Management team with responsibility for long-term strategies in the area of radio-access technologies.

Erik Dahlman is the co-author of the book 3G Evolution – HSPA and LTE for Mobile Broadband. He has also participated in three other books within the area of radio communication, as well as numerous journal papers and conference contributions.

Erik Dahlman holds more than 75 patents in the area of mobile-radio communication.

Course Outline

The tutorial begins with a short overview of the different technologies that exist for 3G wireless communication. This also includes an overview of the related specification and standardization activities technologies.

In the second, main part, of the tutorial, a more detailed description of the different 3G wireless technologies, Wideband CDMA (WCDMA), cdma2000, and UTRA TDD, is given. The main focus is on the physical layer but some higher-layer aspects are also being discussed. Furthermore, the differences between the different 3G technologies are high-lighted.

The third part of the tutorial covers the evolution of the 3G wireless technologies. I this part, WCDMA HSDPA, WCDMA Enhanced uplink, and cdma2000 1xEV is covered.

Course Summary / Key Points

- The aim of this tutorial is to give some insight into the technical details of the different technologies that exists for 3G wireless communication.
- Provide a detailed description of the different 3G wireless technologies, Wideband CDMA (WCDMA), cdma2000, and UTRA TDD, is given.
- Review the evolution of the 3G wireless technologies.

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Outline

The tutorial will start with a short summary of the different technologies that exist for 3G wireless communication. This will also include an overview of the different specification and standardization activities that are ongoing, related to the 3G wireless technologies.
We will then go more into the details of the different 3G wireless technologies. This will cover wideband CDMA, or W-CDMA, the TD-CDMA and TD-SCDMA 3G technologies, and finally the CDMA 2000 technology.

Finally, at the end of the tutorial, we will touch upon the evolution of the 3G wireless technologies. This evolution, which will further enhance and improve the performance and capabilities of the 3G wireless technologies has actually already begun, and it will surely continue also in the future.

Mobile communication – The different generations

If one talks about third generation wireless or mobile communication, it is quite obvious that there exists, or at least must have existed, also first and second generation mobile communication systems, and corresponding first and second generation wireless technologies.

When one talks about first generation mobile communication systems one typically refers to the analog mobile communication systems that were deployed around the world during the 1980s.

These systems included systems based on the AMP standard, developed in North America, systems based on the text standard used, for example, in the United Kingdom, and systems based on the NMT standard jointly developed by the Nordic countries.

These first generation systems were, as mentioned, deployed during the 1980s and were the first mobile communication systems that reached any kind of mass usage.

These systems were limited to provide basically only voice sources and were, as already mentioned, based on analog radio transmission technology.

Starting around 1992 the deployment of second generation mobile communication systems began. The second generation mobile communication systems include systems based on the GSM standard, first deployed in Europe and later on in many other places--basically around the entire world; systems based on the IS-136 standard, mainly deployed in North and South America; PDC systems in Japan; and, somewhat later, systems based on the so-called IS-95 standard.

These systems, especially systems based on GSM, and to a somewhat less extent also IS-95, are actually still the main mobile communication systems being used around the world. The key characteristic of these second generation mobile communication systems was that they, in contrast to the first generation systems, were based on digital transmission technology.

Originally the second generation systems were very much focused on providing mobile voice communication that is, in essence, the same kind of service as the first generation analog systems.

However, the second generation systems have later on been extended with capabilities to provide efficient low and medium rate mobile data services.

Finally, from around 2001, deployment of third generation, or 3G wireless systems has begun. The key characteristics of the third generation systems is that they, in addition to providing all the services of second generation systems, such as high quality voice, also support high speed mobile data communication, with possibility for data rates of several hundred kilobytes per second, all in the first releases of the standards, and as you will see, even much higher data rates in the most recent releases.

This slide also illustrates some other important aspects related to the development, deployment, and usage of mobile communication systems.

First, the deployment of a new mobile communication technology is almost always preceded by an often relatively long lasting phase of research and standardization activities.
As an example, detailed studies on how to apply digital transmission technology to mobile communication, an activity that eventually led to the emergence of second generation mobile communication technology, such as DSM, were actually initiated all within the first half of the 1980s.

In the same way, initial work on third generation mobile communication technologies was actually started already in the first half of the 1990s, almost ten years before the first commercial deployment of third generation systems.

Furthermore, that's not a step wise replacement of one generation of mobile communication systems by the next generation. Instead, different generations typically exist in parallel for several years.

As an example, there are actually still first generation mobile communication systems in operation around the world, simply due to the fact that they are still functioning, and they are still able to provide a service that is being requested by people.

In the same way, systems based on GSM will clearly continue to exist and prosper for many years in parallel to the third generation systems currently being deployed.

3G Wireless Technologies

So what are the technologies that are available for third generation wireless communication? Actually in the same way as there were several different technologies or standards available for first and second generation wireless communication, there are also several different technologies available for third generation wireless communication.

The two main 3G technologies are wideband CDMA, which is also sometimes referred to as UTRA-FDD, and CDMA 2000. Actually as of today these are the only 3G technologies that have reached any kind of really substantial commercial deployment.

However, in parallel to wideband CDMA and CDMA 2000, there are also two so-called TDD based 3G technologies, referred to TD-CDMA and TD-SCDMA. These two technologies are sometimes also jointly referred to as UTRA-TDD.

Finally EDGE, which is a more direct evolution of the second generation DSM standard towards high data rates is actually also regarded as a third generation wireless technology. However, in this tutorial we will not deal further with EDGE, but we will focus on wideband CDMA, CDMA 2000, and the TD-CDMA and TD-SCDMA 3G technologies.

3G Wireless Communication Spectrum

Fundamental to any kind of radio communication is that there is a need for some radio spectrum or frequency band to operate in.

The task of identifying spectrum for different types of radio access communication lies at the World Radio Conference, WRC. Actually already as early as 1992 WRU, which was then known as WARC, identified spectrum for third generation mobile communication.

More specifically, a total of 170 megahertz of spectrum in a 2 gigahertz band was identified for third generation mobile communication. This spectrum is often referred to as IMT 2000 core band.

Actual 3G Spectrum Allocations

However, in the end it is actually up to the authorities or regulators of each country to decide what each part of the overall radio spectrum in a certain country should be used for.
It turned out that in both Europe and in Japan the decision was to really use most of the identified IMT 2000 spectrum for new, third generation mobile communication.

As we can see from this figure, the only exception was some part of the lower end of the IMT 2000 spectrum that was already being used for so-called cordless systems, based on the so-called DECT and PHS technologies.

However, as we can see in North American the situation was very different. In North America a large part of the identified IMT 2000 spectrum had already, during the 1990s, been allocated and even issued to operators for so-called personal communication systems. These PCS systems are second generation mobile communication systems typically based on the DSM or IS-95 wireless technologies.

This created a situation where the conditions for third generation mobile communication were very different in Europe and Japan, on the one hand, and in North America on the other hand. As we see later, this was one of the main reasons why one, in the end, ended up with multiple 3G technologies.

3G Technologies – Where Are They Specified?

So who is actually making the different 3G wireless technologies? Actually the task of making or specifying the different 3G technologies that is to preclude on the actual technical details of each technology have been given to two organizations, known as 3GPP and 3GPP2.

First, the so-called Third Generation Partnership Project, or 3GPP, was created to specify the wideband CDMA 3G technology. 3GPP is also specifying the two TDD technologies; TD-CDMA and TD-SCDMA.

Somewhat later, 3GPP2, or the Third General Partnership Project 2 was created to specify the CDMA 2000 3G technology.

Relation to Regional Standardization Bodies

3GPP and 3GPP2 are the organizations that make the actual technical work or the technical specification of the different 3G wireless technologies.

However, 3GPP and 3GPP2 do not define any formal standards. This is a standard task of regional standardization bodies such as Arribe in Japan, CWTS in China, ETSI in Europe, TTI in Korea, and TIA and T1 in North America.

One can say that instead of specifying or defining their own regional standards, these different standardization bodies use 3GPP and 3GPP2 to create joint global specifications. The specifications developed by 3GPP and 3GPP2 are then fed back to the regional standardization boards in order to be formally approved as, for example, an ETSI standard or an Arribe standard.

From this figure one can also note that Arribe, CWTS, and TTI are actually members of both 3GPP and 3GPP2. This reflects the fact that both wideband CDMA and CDMA 2000 are deployed, or at least expected to be deployed in the corresponding regions that is in Japan, China, and Korea. For this reason, both wideband CDMA and CDMA 2000 must, for example, be defined as Arribe standards.

3GPP/3GPP2 – Relation to ITU

Finally we have the relation between 3GPP and 3GPP2 on the one hand, and ITU. ITU is the global organization that formally defines IMT 2000. That is the global third generation standard.

However, in practice this just implies that ITU put what we can call an IMT 2000 stamp on the different 3GPP and 3GPP2 specifications. Thus, all third generation technologies; wideband CDMA, CDMA 2000, TD-CDMA, and TD-SCDMA, and actually also EDGE, are components or different modes of a singular global IMT 2000 standard.

3G technologies – How do they relate to each other?

If one wants to group the different 3G wireless technologies together, this can be done in different ways. In some sense it is natural to group wideband CDMA and the TD-CDMA, TD-SCDMA technologies together, as these technologies are all developed by the same organization that is 3GPP.

Furthermore, there are a lot of higher-layer commonalities between these technologies, simply due to the fact that they're all specified by the same organization.

Finally in practice these 3G wireless technologies or radio access technologies will typically be connected to the same type of core network.

Actually wideband CDMA radio access networks typically connect to the same core network as is being used for second generation DSM networks.

CDMA 2000, on the other hand, is developed by different organizations that is 3GPP2, has a different higher-layer structure, and is typically connected to a different type of core network compatible wideband CDMA.

However, as we will see later, on the physical layer there are actually major differences between wideband CDMA and the TD-CDMA, TD-SCDMA wireless technologies.

3G technologies – Alternative view

On the other hand, as will also be apparent later on, from a physical layer point of view, wideband CDMA and CDMA 2000 are actually very similar technologies, and at the same time, very different from TD-CDMA and TD-SCDMA. This also means that in the end wideband CDMA and CDMA 2000 will actually behave quite similar, and have similar performance, in many cases.

3GPP Wireless Technologies

We will now look further into details of the different 3G wireless technologies. We will start with technologies developed by 3GPP, that is wideband CDMA and the TD technologies, TD-CDMA and TD-SCDMA.

These technologies also go under the joint name of UTRA or UMTS terrestrial radio access. The term UMTS, which is also sometimes used for third generation mobile communication is actually a more wide term that does not only cover the 3G radio access technologies, but also the corresponding core network technology.

Process towards 3GPP wireless technology

The development of the UTRA 3G wireless technologies, especially wideband CDMA, was very much the result of cooperation between Europe and Japan, and also, to some extent, Korea.

Process towards UTRA technology decision

This slide illustrates the background to the decision of 3G wireless technology in Europe, more specifically the process in the European standardization body, ETSI, to conclude under UTRA radio access technology.

Initially there were several competing 3G technology proposals submitted to ETSI. Several of these proposals originated from the European Union sponsored research project, Frames. The two main proposals were the so-called Alpha concept and the Delta concept. Both these technology proposals were initially developed within the Frames project.

As can be seen, the Alpha concept was based on so-called wideband CDMA or W-CDMA radio access technology, while the Delta concept was based on a technology referred to as TD-CDMA.

In ETSI the Alpha concept was primarily promoted by the two largest European wireless communication equipment manufacturers, Ericsson and Nokia. However, there were also substantial contributions to the Alpha concept from different Japanese companies. The reason was that--the reason for this was that in Japan there was already work ongoing on the third generation wireless communication technology, also based on the wideband CDMA technology.

This Japanese 3G technology proposal was, all the way from the start, quite similar to the Alpha concept, and during the entire time, the 3GPP work was intense effort by Ericsson, and Nokia, and different Japanese companies to further line the European and Japanese wideband CDMA technologies in order to eventually arrive at the common European, Japanese 3G wireless technology.

The Delta concept, on the other hand, was promoted by several other major manufacturers, including Siemens, Alcatel, Nortel, and Motorola.

After an intense discussion and evaluation phase in ETSI, which lasted for more than a year, it was concluded that the fight between the two major competing proposals could not be resolved without a formal vote.

This vote took place in Paris in the beginning of 1998. As we can see, the result was a clear majority in favor of the Alpha concept, that is that the ETSI 3G technology should be based on the wideband CDMA technology.

One main reason for this was that many operators saw, in the Alpha concept, that is in wideband CDMA, the possibility to reach a truly global 3G standard.

However, due to the ETSI voting rules, the majority in favor of the Alpha concept was not sufficient for an all out victory. Instead a compromise was needed in order to reach a final ETSI decision on the 3G technology.

ETSI decision on UTRA technology

According to the ETSI decision on 3G technology, the wideband CDMA radio access technology developed by the Alpha group should be used in the larger part of the 3G or IMT 2000 spectrum.

However, within a smaller part of the spectrum the TD-CDMA technology developed by the Delta group should be used.

For reasons that will later on be clear, these different parts of the 3G spectrum are also referred to as the FDD spectrum and the TDD spectrum, respectively. This is the reason why wideband CDMA is sometimes referred to UTRA FDD in the same way TD-CDMA is often referred to as UTRA TDD. The two spectrum parts are also sometimes referred to as PAN and UNPAN spectrum, respectively.

Third Generation Partnership Project – 3GPP

In the next step of the development of the UTRA third generation wireless technology the Third Generation Partnership Project, 3GPP, was created.

The reason for creating 3GPP was to create a global organization that could really ensure the development of a truly global 3G technology.

Within 3GPP the ETSI wireless CDMA technology was merged with the now very similar wideband CDMA technology from Japan, and also with a similar technology from Korea. Note that the name UTRA, that originated ETSI, was adopted also by 3GPP, which meant that this merged wideband CDMA technology, retained the name UTRA FDD.

The TD-CDMA proposal was also introduced in 3GPP, and it then retained the name UTRA TDD.

At the much later stages, a second TDD based 3G technology from China, based on so-called TD-SCDMA technology was also introduced in 3GPP. Eventually this resulted in two UTRA TDD modes; the so-called high ship rate TDD mode and the low ship rate TDD mode. The reasons for these specific labels should become obvious later on during this tutorial.

3GPP Wireless Technologies

In this part of the tutorial we will go more into the details of the 3GPP wideband CDMA technology. That is the technology also known as UTRA FDD.

WCDMA – Key air-interface characteristics

This slide summarizes the most basic characteristics of the wideband CDMA active phase technology.

The wideband CDMA transmission technology is based on direct sequence spreading using a chip rate of 3.84 mega chips per second.

This means that a transmitted wideband CDMA signal will have a bandwidth of roughly 5 megahertz. The wideband CDMA duplex arrangement is based on the frequency division UPIX FDD, and the multiple access scheme is based on code division multiple axis; CDMA. So what does all of this mean?

WCDMA direct-sequence spreading – Basic principle

This slide illustrates the basic principle of direct sequence spreading. Direct sequence spreading simply implies that modulation symbols of a certain symbol rate, or spread, in practice multiplied by so-called spreading code, sometimes also referred to as a spreading sequence.

The rate of the spreading code, which is typically referred to as the chip rate of the spreading code, is normally substantially higher than the rate of the modulation symbols. That is the symbol rate before the spreading.

For example, in case of wideband CDMA, the chip rate is 3.84 mega chips per second, or 3.84 million chips per second. At the same time, the rate of the modulation symbols could be anything from a few thousand symbols per second up to several hundred thousand symbols per second.

Due to this spreading the bandwidth transmitted direct spread signal is typically substantially larger than the basic information rate. Direct sequence spreading thus typically implies a so-called spread spectrum transmission.

The ratio between the symbol rate after spreading, which is the same as the rate of the spreading code, that is the chip rate, and the rate of the modulation symbols, is normally referred to as the spreading factor.

As an example, in wideband CDMA the chip rate is, as mentioned, 3.84 mega chips per second. On the other hand, the symbol rate before spreading may vary from 50 kilo symbols per second, or 15,000 symbols per second, up to 960 kilo symbols per second, or 960,000 symbols per second

The wideband CDMA spreading factor comes up the range from 256 for the lowest symbol rate down to 4 for the highest symbol rate.

WCDMA – Theoretical spectrum

The wideband CDMA chip rate, together with the pulse shaping filters of the transmitter, determines the spectrum shape of the transmitted wideband CDMA signal.
According to the CDPP specification, the wideband CDMA pulse shaping filter should have a so-called road raised cosign shape, implying that the spectrum will have a raised cosign shape.

At least in theory this results in spectrum with a transmitted signal, according to this figure. It should be noted that all of the wideband CDMAs typically set to have a bandwidth of 5 megahertz. The actual bandwidth is actually somewhat smaller. There is always a question on exactly how to define the bandwidth.

As we can see from this figure, the 3 DB bandwidth, or the wideband CDMA signal is actually exactly 3.84 megahertz. That is equal to the wideband CDMA chip rate.

WCDMA – Real spectrum (example)

In practice, imperfection in transmitter chain will of course lead to expect a difference at least somewhat from the theoretical spectrum shown in the previous slide. An actual wideband CDMA signal may, for example, have a spectrum according to this figure.

We can note from these figures, at the main part of the wideband CDMA spectrum really nice within the 5 megahertz bandwidth.

Duplex arrangement

We have several times mentioned the abbreviations FDD and TDD. We will now describe what is really meant by this.

FDD stands for Frequency Division Duplex, while TDD stands for Time Division Duplex. These terms are used to describe different so-called duplex arrangements. That is, different means by which we can separate downlink and uplink transmissions from each other. That is, separate a transmission from the base station to the mobile terminal, from the transmission from the mobile terminal to the base station.

Frequency Division Duplex, or FDD, simply means that this separational downlink and uplink transmissions is done in the frequent domain. That is, different frequency bands are used for the downlink and uplink transmissions.

Time Division Duplex, or TDD, on the other hand, means as these separational downlink and uplink transmissions is done in the time domain, that is different non-overlapping timeslots are used for downlink and uplink transmission.

Duplex arrangements

This slide illustrates the difference between Frequency Division Duplex and Time Division Duplex in somewhat more detail. We can see that Frequency Division Duplex, or FDD, implies separation in the frequency domain. That is, different frequency bands, or a pair of frequency bands are used for uplink and downlink transmission.

On the other hand, Time Division Duplex, or TDD, implies separation in the time domain. That is, different timeslots are used for uplink and downlink transmissions. Thus, in case of Time Division Duplex, only a single frequency band is needed. This frequency band is then used for both downlink and uplink transmission.

Examples on wireless systems utilizing Frequency Division Duplex are all first and second generation cellular systems that is AMPS, TACS, DSM, IS-95, et cetera.
Among the 3G wireless technologies, wideband CDMA and CDMA 2000 are both based on Frequency Division Duplex. This is of course the reason why wideband CDMA is sometimes referred to UTRA FDD.

Examples of wireless systems based on Time Division Duplex are cordless systems, such as DECT and PHF in Japan.

Among the 3G wireless technologies, TD-CDMA and TD-SCDMA are based on Time Division Duplex. This is then of course the reason why these wireless technologies are sometimes referred to as UTRA TDD.

WCDMA – Spectrum allocation

According to the ETSI decision on 3G technology, the frequency bands from 1,920 megahertz to 1,980 megahertz, and from 2,110 megahertz to 2,170 megahertz should be used for wideband CDMA.

These frequency bands are thus used for two way transmission by means of Frequency Division Duplex. The lower frequency band, from 1,920 megahertz to 1,980 megahertz is used for uplink transmission. That is, for transmission from the mobile terminal to the base station.

At the same time, the higher frequency band, from 2,110 megahertz to 2,170 megahertz is used for downlink transmission. That is, for transmission from the base station to the mobile terminal.

In each of these bands there can be up to 12 wideband CDMA carriers. Typically the spectrum is divided between operators so that each operator has, for example, 15 megahertz of spectrum in the uplink band and 15 megahertz of spectrum in the downlink band. This then allows for up to 3 uplink carriers and 3 downlink carriers per operator.

Multiple-access scheme

A second key characteristic of mobile communication systems is the multiple access scheme. That is, the method by which different transmissions or different communication links can exist in the same area.

To be more specific, we should actually distinguish between two aspects, or multiple access. First, how to separate different communication links within one cell. This can also be referred to as intracell multiple access.

Second, how to separate different communication links in neighbor cells. This can also be referred to as intercell multiple access.

We also have to consider both the downlink multiple access scheme. That is, how to separate different downlink communication links, and the uplink multiple access scheme. That is, how to separate different uplink communication links.

Basic multiple-access schemes

There are three basic schemes for multiple access; FDMA, TDMA, and CDMA.

In case of FDMA, or Frequency Division Multiple Access, separation of different communication links is done in the frequency domain. This means that different communication links are transmitted in different frequency bands. That is, in practice they are transmitted using different carrier frequencies.

Examples of mobile communication systems using FDMA are all the first generation analog systems. For analog systems by advanced digital signal processing is not possible. FDMA is, in essence, the only possible multiple access scheme.

In case of TDMA, or Time Division Multiple Access, separation of different communication links is done in the time domain. This means that each communication link is allocated one of a set of so-called timeslots.

Examples of mobile communication systems using TDMA are the second generation systems based on the GSM, PDC, and IS-136 standards.

As an example, in GSM there are eight timeslots per frame, and thus eight users can share one carrier frequency by means of a TDMA.

Both FDMA and TDMA are what we could call orthogonal [phonetic] or interference free multiple access schemes. In the sense that the signal is being transmitted using different carrier frequencies, in case of FDMA, or in different timeslots, in case of TDMA do not, at least in theory, cause any interference to each other.

The third alternative for multiple access is CDMA, or Code Division Multiple Access. In case of CDMA, separation of different communication links is done by spreading each signal by means of different spreading codes.

This spreading process was all illustrated already on Slide 2-3. As already mentioned, due to this spreading, the bands that transmit a signal is typically much larger than the rate of the information signal. CDMA thus implies spread spectrum transmission.

It should here be noted actually also TDMA implies a kind of spread spectrum transmission. In case of TDMA, data obviously needs to be compressed in time to fit into a single timeslot. This means that when data is actually transmission in a timeslot it is transmitted with a higher data rate. That is, it needs a wider bandwidth that is spread spectrum transmission.

As we will see later, spreading in a CDMA system can be done either by means of so-called orthogonal spreading codes, in which case at least in theory there will be no interference between different, parallel transmissions.

Alternatively spreading can be done by no orthogonal spreading codes. In this case there will be done remaining interference between the different transmission.

However, this interference is suppressed by the so-called processing gain, or the bandwidth expansion of the system. That is, the more spreading that is the wider bandwidth, the more interference suppression.

Finally it should be noted that systems based on TDMA and CDMA, in almost all cases, also include an FDMA component. As an example, in DSM up to eight users can share 1 to 200 kilohertz carrier frequency by means of TDMA.

However, there can be many such 200 kilohertz carrier frequencies in one cell. Each such carrier frequency is then shared by up to eight users by means of TDMA.

In this sense the assembly is actually a combination of TDMA and FDMA.
Similarly, in wideband CDMA single source spread to a bandwidth of approximately 5 megahertz, and there can be a large number of users sharing this bandwidth by means of CDMA.

However, there may very well be, and often will be, more than one 5 megahertz wideband CDMA carrier in a cell. If this is the case, users being transmitted on different carriers are, strictly speaking, separated by means of FDMA.

WCDMA spreading – Overall structure

This slide describes the wideband CDMA spreading in somewhat more detail. As can be seen, the wideband CDMA spreading actually consists of two steps.

In the first step, modulation symbols are spread to the chip rate. That is, the 3.84 mega chips per second by means of a so-called orthogonal code.

This spread signal is then scrambled by a random code. Note that the scrambling is not really a spreading process, as the chip rate after scrambling is actually the same as before the scrambling. The reason for the scrambling is simply to randomize the signal before transmission.

The reason for using this two step approach with spreading plus scrambling is that the spreading process actually serves two purposes.

The spreading should separate different users within the same cell. This is the intra-cell multiple access function. But the spreading should also separate different users in neighbor cells. This is the inter-cell multiple access function.

How this is done and how this is related to the different spreading and scrambling codes will be described in more detail in the next few slides.

It should also be noted that the total spread--spectrum spreading, or what is known as the processing gain of the system actually also includes channel coding.

As an example, for 8 kilobits per second voice service, a spreading of 256 can be used for wideband CDMA. However, the processing gain, which is defined as the ratio between the transmission bandwidth and the information bit rate is, in this case, 384 megahertz divided by 8 kilobits per second, that is 480, or around 27 dB.

Note that we here assume that the wideband CDMA transmission bandwidth is 3.84 megahertz. The reason for using 3.84 megahertz instead of 5 megahertz to calculate the processing gain is that the wideband CDMA 3 dB bandwidth, which is the most relevant bandwidth, when calculating the processing gain, is actually exactly 3.84 megahertz. This we can also see from this spectrum, or Slide 2-4.

WCDMA – Downlink spreading/scrambling

This slide illustrates the use of the different codes in the wideband CDMA downlink direction. That is, in case of transmission from the base station to the mobile terminates.

As can be seen, in a downlink direction the orthogonal spreading code is used to separate different downlink transmissions within one cell.

This means that different spreading codes are used for different downlink communication links, or channels within one cell.

For this reason the wideband CDMA spreading codes is also sometimes referred to as the channelization code.
At the same time, all downlink transmissions within the cell is scrambled by the same scrambling code.

On the other hand, the non-orthogonal scrambling code is used to separate communication links in neighbor cells. This means that transmissions from different base stations use different scrambling codes.

At the same time, as we see from this figure, the same channelization code can be used for two communication links in neighbor cells.

There are a total of 512 downlink scrambling codes available wideband CDMA. This means that scrambling codes can be allocated or assigned to base stations more or less on random. There is simply very little probability that the same scrambling code should, by chance, be allocated to two base stations close to each other.

As a consequence, the effort of allocating or assigning scrambling codes to base stations is very limited.

WCDMA – Uplink spreading / scrambling codes

On the other hand, for the uplink transmissions, all mobile terminals, both within one cell and in different cells, use different scrambling codes.

The orthogonal spreading codes, on the other hand, is for the uplink only used to separate control signaling and data transmission from the same mobile terminal.

The design on the uplink scrambling code in wideband CDMA is such that there many millions of uplink scrambling available. The risks that two mobile terminals close to each other, that is, in the same cell or in cells close to each other, should, by accident, use the same scrambling code is extremely small.

Once again then, as a consequence there is in essence no effort in allocating or assigning different scrambling codes to different mobile terminals.

Downlink orthogonal code resource

The orthogonal codes used in wideband CDMA, or so-called voice codes of variable lengths. They are also sometimes referred to as Orthogonal Variable Spreading Factor codes, or OVSF codes.

These are codes can be of different lengths, depending on what spreading factor is needed. Note that the spreading factor depends on what data rate is needed. That is, a higher data rate requires a lower spreading factor.

This is obvious from the fact that the product of the modulation symbol rate, the spreading factor, equals the constant chip rate. Thus, the higher data rate, the higher symbol rate, and thus the lower spreading factor.

As illustrated in this figure, there's a limited number of orthogonal codes available. Also, the number of available codes depends on the spreading factor.
The maximum wideband CDMA spreading factor is 256, and there are then a maximum of 256 orthogonal codes. In case of a lower spreading factor, the number of codes is less. For example, there are a maximum of 32 orthogonal codes, or spreading factor 32, or a maximum of 8 orthogonal, or spreading factor 8.

One can also express it so that each code of a certain spreading factor can be replaced by two codes of twice the spreading factor.

However, each of these codes can then only carry a symbol rate that is half that of the original code.

As an example, a code of spreading factor 4 can be replaced by 2 codes of spreading factor 8. Each will assimilate half that of the spreading factor 4 code.
Thus, the total symbol rate that can be carried by the total set of codes is constant, independent of the spreading code factor.

However, with the higher spreading factor that total symbol rate is split between more codes, each with a lower rate.

Variable-length Walsh codes – Example

This slide exemplifies the wideband CDMA orthogonal codes in slightly more detail. As an example, there are 4 orthogonal codes of length 4. That is, codes that can spread data with a spreading factor 4.

Note that all the codes are orthogonal to each other. This simply means that if one calculates the cross correlation between two of these codes, the result is always zero.
If one instead assumes a spreading factor of 8, there are 8 orthogonal codes assumed in the lower figure. Thus for a spreading factor of 8 one could have up to 8 downlink transmissions within one cell.

However, each of these transmissions would only carry half the symbol rate, compared to if a spreading factor of 4 is used.

Finally one can also have a mix of spreading factors in a cell. For example, 2 transmission with a spreading factor of 4, and 4 transmissions with a spreading factor of 8. That is in total 6 transmissions.

However, once again the total overall symbol rate of all of these codes is the same.

Orthogonal vs. non-orthogonal intra-cell separation ?

It is clear from the discussions until now that there is a difference in how communication links are separated on downlink and uplink, in case of wideband CDMA.

For the downlink, orthogonal codes are used to separate different communication links within the same cell.

On the other hand, for the uplink, random, that is non-orthogonal codes, are used to separate communication links, also within one cell.

So why this difference? The key benefit of orthogonal codes is that there is, at least in theory, no interference whatsoever between the different communication links.
In contrast, with random codes the interference is only suppressed by the processing gain. That is, there’s always some residual interference.

As a consequence, the usual orthogonal codes for the downlink leads to high capacity, as there will be no, or at least a reduced interference from their own cell. That is, reduced intracell interference.

It should be pointed out though, that this orthogonality, in case of orthogonal codes, is partly destroyed in case of a time dispersive channel.

Thus in case of a time dispersive radio channel there will be some interference between communication links within one cell, even if orthogonal codes are used.

The drawback of orthogonal codes is that, as we have seen in the previous slides, there is only a limited number of orthogonal codes available.

This means that in some cases capacity may actually be hard limited by the number of available codes, rather than being interference limited.

This may happen, especially if codes are allocated, but not extensively used. This may, for example, be the case in burst of data transmission.

Orthogonal codes avoid interference only in the case of synchronous transmission. The uplink transmission from different users are not synchronized. Thus there will be no benefit of using orthogonal codes in the wideband CDMA uplink.

At the same time, by separating users by means of random codes, one avoids the problem of allocating a limited number of codes to the different users. As there are almost infinitely amount of random codes, the uplink code allocation or code assignment then becomes very simple.

Some other WCDMA features

We will now discuss some other key technical aspects of wideband CDMA. Most specifically power control, transmit and soft hand over.

SLIDE 35 - WCDMA – Power control

Power control is an important function in most CDMA based mobile communication systems, especially in the case of non-orthogonal use separation. That is when on relies on processing gain go suppress the interference from other users which is, for example, the case for the wideband CDMA uplink.

The reason is, at least in this case, is the capacity of a CDMA system is typically interference limited.

This means that fully uplink, it is very important that transmissions from mobile terminals are received at the base station with the correct signal to interference ratio, or in practice, the correct received power.

If the signal to interference ratio, the received signal is too low, the service quality, for example the speech quality, will obviously not be sufficient. There will simply be too many incorrect speech frames.

On the other hand, if the signal to interference ratio received signal is too high this means that the transmit power is unnecessarily high. As a consequence, there will be unnecessarily high interference to other communication links, and thus reduced capacity. One can also express it so that a user, by being received with an unnecessarily high power, that is having unnecessarily good quality, he then uses an unnecessarily large part of the overall cell capacity.

As the channel conditions, including path loss and fading is continuously varying, it is therefore important to continuously adjust the transmit power of the mobile terminal to compensate for these channel variations, and thus to keep the received signal to interference ratio relatively constant at an approximately constant level.

This so-called power control is done by having the base station continuously measuring the received signal to interference ratio and compare these to a threshold.

This threshold can be seen as the decide signal to interference ratio. If the received signal interference ratio is above the threshold, the base station orders the mobile terminal to reduce the transmit power a certain amount, for example 1 dB.

On the other hand, if the received signal to interference ratio is below the threshold, the base station instead orders the mobile terminal to increase the transmit power.

This so-called power control is typically carried out in the order of once every millisecond. For the uplink, power control is really necessary as the path loss between the mobile terminal and the base station can vary significantly, depending on the position of the mobile terminal within the cell.

As an example, if all mobile terminals were transmitting with the same power, the transmission from a mobile terminal close to the base station would be received with much higher power compared with transmission from a mobile terminal far from the base station. This is also known as the near:far effect.

For the downlink, that is in case of transmission from the base station to the mobile terminals, there is not really such a near:far as all downlink transmissions in the cell actually originate from the same point. That is, from the base station. However, power control is still used on the wideband CDMA downlink.

The main reason for downlink power control is wideband CDMA is to compensate for so-called fast multipass fading on the radio channel. In this way the link modules needed against fast fading can be reduced, and this then allows for an on average lower transmit power, and thus reduced interference to other cells.

WCDMA – Downlink transmit diversity

In general, diversity is very important in most cases of radio communication. In essence diversity means that data is, in some way or another, transmitted over multiple radio channels or multiple radio paths.

The goal with diversity is to reduce the impact of fading on the radio channel. The basic idea is that if one radio path momentarily suffers from bad fading, that is unusually bad channel conditions, another path is, with a high probability, not suffering from a fading dip. That is, not suffering from bad channel conditions at the same time.

Receiver diversity for the uplink, that is the use of multiple receiver antennas at the base station, has been used for many years. By using multiple antennas for reception, one gets both diversity gain, in the sense that the signals received at the two antennas have propagated via two different paths at time, hopefully experience different, independent fading. However, receiver diversity also gives an SIR, or power gain in the sense that the received signal is received by two antennas, thus in essence the--twice as much energy is being collected.

Receiver diversity for the downlink would imply multiple antennas and multiple receiver chains at the mobile terminal. In many cases this is not very attractive, at least not for low cost handle terminals. For that reason, the possibility for other means of diversity is desirable.

Thus, wideband CDMA specification includes different methods for downlink transmit diversity. That is the means by which downlink diversity is achieved by using two transmit antennas at the base station.

There are two different schemes for transmit diversity being specified for wideband CDMA; closed loop transmit diversity and open loop transmit diversity.

WCDMA – Closed-loop transmit diversity

In case of closed loop transmit diversity the same signal is transmitted from two antennas at the base station. However, the phase and amplitude of each antenna are adjusted based on the information fed back by the mobile terminal. This is the reason for the name closed loop transmit diversity.

The phase and amplitude of the two antennas are adjusted so that the two transmissions add up constructively. That is, in phase at the position of the mobile terminal.

In this way there is both a diversity gain and an SIR gain, that is a maximization of the received power at the mobile terminal. Closed loop transmit diversity can thus be seen as a kind of simple adaptive beam forming.

The drawback of closed loop transmit diversity is that it can obviously only be used for dedicated channels. That is, in case of transmission that is directed to a single mobile terminal, not in case of common channel transmission. That is, transmission that are directed to multiple terminals at the same time.

Another problem is that the feedback information may not be able to track the channel variations if the mobile terminal is moving at a high speed. Thus closed loop transmit diversity is especially suitable for low mobility scenarios.

WCDMA – Open-loop transmit diversity

Open loop transmit diversity in wideband CDMA is based on so-called space time codes. More specifically, the wideband open loop transmit diversity scheme is a modification of a relatively well known so-called Alamouti codes.

In essence, two modulation symbols are transmitted unmodified on the first antenna. However, on the second antenna the two modulation symbols are transmitted in a somewhat modified form, and also in reverse order.

In this way a diversity effect can be achieved at the receiver, assuming that a suitable receiver algorithm is being used.

However, in contrast to closed loop transmit diversity, open loop transmit diversity does not give any SIR or power gain. On the other hand, both dedicated and common channels can benefit from open loop transmit diversity.

WCDMA – Soft handover

Soft turnover is another key feature of wideband CDMA. In essence, soft maneuver means that mobile terminals that are close to the border between two cells communicate with base stations of both cells at the same time.

On the uplink, soft turnover simply means that the mobile terminal transmission is received at both base stations. At the same time, the mobile terminal is power controlled from both base stations. As long as least one base station orders the mobile terminal to lower the transmit power, the mobile terminal transmit power should be reduced.
In this way it is ensured that the mobile terminal is not received with too high a power at any of the base stations. Note here that it's sufficient that the mobile terminal transmission is received with sufficient power at at least one base station.

As long as data is correctly decoded at one base station, the so-called RNC, or radio network controller, can select data from this base station and send this data further up into the network.

For the downlink, soft turnover means that both base stations transmit the same information to the mobile terminal. The two signals are then combined in the mobile terminal receiver.
For the uplink there's a clear benefit of soft turnover. First there is a diversity gain as the signal is transmitted over two hopefully independently fading paths.
Second, there is a basic SIR, or power gain due to the fact that the same received signal is actually received at two places by two different antennas.

For downlink, on the other hand, there is no power gain or soft turnover, as there are actually two signals being transmitted, one from each base station. Thus, the transmit power of each signal need to be reduced in order to avoid an increased overall interference level.
However, there is still a diversity benefit of downlink soft turnover.

3GPP Wireless Technologies

In this third part of the tutorial we will give an overview of the 3GPP TDD technologies. That is TD-CDMA and TD-SCDMA.
As already mentioned these two technologies are also sometimes jointly referred to as UTRA TDD.

TD-CDMA

We will start with TD-CDMA, which stands for Time Division Code Division Multiple Access.

TD-CDMA – Key air-interface characteristics

This slide shows the most basic characteristics of the TD-CDMA radio access technology. As can be seen, TD-CDMA differs in some fundamental aspects from wideband CDMA. In contrast to wideband CDMA, TD-CDMA is based on time division duplex that is downlink and uplink transmissions take place on different timeslots on the same carrier frequency.

Furthermore, TD-CDMA multiple access is based on a combination of time division multiple access and code division multiple access.

At the same time, some of the most basic parameters of TD-CDMA, such as the chip rate, bandwidth, frame length, et cetera, have been harmonized to the use of wideband CDMA. This was done as part of the Paris Agreement on UTRA technology. The reason was to simplify the implementation of UL mode mobile terminals supporting both wideband CDMA and TD-CDMA.

UTRA/TDD – Spectrum allocation

According to the ETSI decision on 3G technology, the frequency bands from 1,900 megahertz to 1,920 megahertz, and from 2,110 megahertz up to 2,125 megahertz, that is in total 35 megahertz spectrum, should be used for TD-CDMA.

This spectrum is therefore known as the TDD spectrum. TDD spectrum is also sometimes referred to as UNPAD spectrum, while FDD spectrum is referred to as PAD spectrum.

TD-CDMA – Key characteristics

One of the key characteristics of TD-CDMA is, as already mentioned, that the multiple access scheme is based on a combination of TDMA, that is time division multiple access, and CDMA.

In practice, for TD-CDMA this means that each ten millisecond frame consists of 15 timeslots. However, in contrast to normal TDMA, such as for DSM, where each timeslot can only be used by one user at a time, there can be up to 16 users or 16 channels transmitted in parallel within each timeslot.

These transmissions are separated by being spread by 16 different codes that is separation within each timeslot is done by means of CDMA.

If high data is only needed for one user that can either be achieved by transmitting on multiple timeslots for one user, or on multiple codes for one user.
Now, it should be remembered that CDMA is a TDD system. Thus, some of the timeslots in each frame are used for downlink transmission, and some timeslots are used for uplink transmission. However, this cannot really be seen in the figure.

TD-CDMA vs WCDMA

This slide just compares the TD-CDMA multiple access with that of wideband CDMA. As can be seen, while separation of different communication links, or channels, in TD-CDMA is done in both the code domain and the time domain, separation of different communication links is the only downlink in code domain for wideband CDMA.

Why combined TDMA/CDMA?

So what are the possible reasons to apply a multiple access scheme that is a combination of TDMA and CDMA, instead of either TDMA or CDMA?

First, why CDMA? That is, why not just TDMA. That is a system where one user at a time has access to the channel.

Well, there are several reasons for applying CDMA to wireless communication. First, the use of CDMA makes it more easy to benefit from so-called statistical averaging, or statistical multiplexing.

In essence, this means that it is easy to utilize the fact that, for example, a speech user is typically not using his cell continuously, but with a certain so-called voice activity.

For example, typical users only speaking during approximately 40 percent of the call. That is, as a voice activity of 40 percent. Utilization of statistical averaging allows for a higher overall system capacity. That is, more users that can simultaneously be served by the system.

The second argument against TDMA is that it leads to a lower duty cycle of a transmitted signal. In essence, in case of TDMA, each user is only using the channel for a small fraction of the total time. As a consequence, when the user is actually using the channel, he or she needs to transmit with a higher rate, and thus a corresponding higher instantaneous transmit power.

This may lead to coverage problems. That is, the mobile terminal may simply not have sufficient transmit power available.

Alternatively speaking, in a CDMA based system where multiple users transmit at the same time, each user may transmit with a lower peak power, leading to recovery benefits.

This problem of TDMA systems is more seriously with wider bandwidth, such as 3G systems, compared with, for example DSM.

In DSM there are eight voice users per carrier. For 3G systems the transmission bandwidth is much larger. This means that one would have many more voice users per carrier and a corresponding lower TDMA duty cycle, and thus a higher peak power.
One may then ask whether TD-CDMA proposal also included a TDMA component. To understand this, one has to understand that the people that originally came up with the TD-CDMA technology anticipated that so-called multi user detection, or MUD, should be used at the receiver.

The multi user detector implies a more complex receive structure compared to the receiver structures currently typically assumed for CDMA based systems.

In case a multi user detection is interferes from other users is not just seen as random interference. Instead, a detector tries to detect all received signals jointly.

The complexity of such a detector obviously grows very rapidly with the number of users to detect. Thus in order to limit the number of users that were simultaneously received, a TDMA component was introduced for TD-CDMA.

TD-CDMA – Key characteristics

The second key characteristics of UTRA TDD,or TD-CDMA, is that it's based on time division duplex. That is downlink and uplink transmissions take place on the same carrier frequency, but in different timeslots.

It should be noted though, which is also shown in this figure, that all codes used during the same time zones are always transmitted in the same direction. That is, either in the downlink direction or in the uplink direction.

The base station simply cannot transmit on some codes on the downlink and, at the same time, receive on some other codes in the same frequency band on the uplink. In that case, the very strong transmittal signal will completely block the base station receiver.

However, although this slide indicates that every second timeslot is used for uplink transmission and every second timeslot is used for downlink transmission, this is not really necessary. One could, for example, use more timeslots for the downlink transmission compared to the uplink transmission. We will discuss this a little bit further on.

TDD benefits/drawbacks

There are both benefits and drawbacks of time division duplex, compared to frequency division duplex. The most obvious benefit with time division duplex is that only a single frequency band is needed.

This is in contrast to frequency division duplex, where two different frequency band, or PAD frequency bands are needed, one for the uplink transmissions and one for the downlink transmission.

This obviously puts additional requirements on a spectrum allocation in case of frequency division duplex.

A second benefit of time division duplex is that there is not a same need for a duplex filter in the mobile terminal as for frequency division duplex.
In case of frequency division duplex, a duplex filter is needed to separate the uplink and downlink transmissions. That is, to ensure that the mobile terminal reception is not interfered with a simultaneously ongoing mobile terminal reception.
However, in case of time division duplex the terminal does not receive and transmit at the same time, so such a duplex filter is not needed.

In practice, the duplex filter is in case of time division duplex replaced by switch. The switches can turn on between the transmitter and the receiver.

Finally it is at least sometimes claimed that time division duplex has some benefits in terms of being able to better support so-called asymmetric traffic conditions. As we'll see later, this is only partly true, though.

The main drawback of time division duplex is it may create some severe interference problems that restricts or at least complicates the deployment of TDD based systems.
This is especially the case in case of deployments using large cells. This will be further illustrated in the next slide.

Interference in TDD system

The important difference, in terms of interference between FDD and TDD based wireless systems is that in systems based on time division duplex there may be direct terminal to terminal and direct base station to base station interference.

In a system based on frequency division duplex, mobile terminals are transmitting and receiving in different frequency bands. This means that the transmission from one mobile terminal will not cause substantial interference to the receiver of another mobile terminal. In the same way the transmission of a base station will not cause any substantial interference to the receiver of another base station.

On the other hand, in systems based on time division duplex, all transmission and reception takes place in the same frequency band. Thus, the transmission from one mobile terminal can cause interference to the receiver of another mobile terminal in a neighbor cell.

The problem is that two mobile terminals in neighboring cells can actually be relatively close to each other, especially if the two terminals are close to the cell border. The distance between them can be much shorter than the distance to the base stations.

One terminal may then be transmitting with high power to reach its base station. This strong transmitted signal may enter the receiver of a nearby mobile terminal in a neighbor cell. This will make it impossible in this mobile terminal to receive the relatively weak signal received from its base station. Thus this kind of direct terminal interference can be very severe.

In the same way, in a system based on time division duplex, the transmission from one base station may cause interference to the base station receiver of a neighbor cell.

Of course, one may argue that the distance between two base stations is typically quite large, and at least as large as the distance from a mobile terminal to a base station.

However, base stations are often placed at relatively high locations and there is thus a risk that two base station locations can be in more or less line of sight of each other. Thus, the pass loss between the two base stations can be relatively low, and there may be substantial interference from base station to the other base station.

TDD – Inter-cell synchronization

One way to avoid these interference problems is in systems based on time division duplex, is to apply tight intercellular synchronization.

If neighbor cells are synchronized to each other it can be ensured that the downlink and uplink timeslots do not occur at the same time in neighbor cells. Thus it can be assured that the mobile terminal in one cell does not transmit while the mobile terminal in a neighbor cell is receiving.

Similarly it can be shown that the base station in one cell does not transmit when the base station in a neighbor cell is receiving.

However, it should be noted that such synchronization may not only be required between cells using the same carrier frequency. Due to imperfections in transmitter receiving filtering, such synchronization may actually also be needed between neighbor carriers.

It should be noted that, in the case of large cells this kind of time alignment can be difficult to achieve over the entire cell due to propagation delays.

As a minimum, relatively large guard bands may be needed between uplink and downlink timeslots to compensate for the propagation delays.

TDD – Support for assymetric traffic

As already mentioned, it is often claimed that wireless systems based on time division duplex have a benefit in terms of support for asymmetric traffic. First we need to understand what we mean with asymmetric traffic and why it may be important.

In essence, it is often expected that future traffic will be asymmetric in the sense that there may be more traffic, in essence more bits per second in the downlink direction. That is, from the base station to the mobile terminal, compared to the uplink direction.

This is simply the consequence of the fact that more and more traffic in the mobile communication systems is expected to be greater traffic.

For example, wave browsing, file transfer, et cetera, and it’s reasonable to assume that, for example, web browsing implies that the amount of data being transmitted on a downlink totally mobile terminal is larger than the amount of data being transmitted on the uplink from the mobile terminal.

This means that the capacity requirement may be different for downlink and uplink. More specifically it is typically expected that more capacity will be needed for the downlink, compared with the uplink.

However, the exact asymmetry relations is very difficult to predict as this, to a large extent, depends on future user behavior and also the characteristics of future, today unknown, services.

For systems based on frequency division duplex the overall uplink and downlink capacity very much depends on the amount of spectrum that has been allocated for uplink and downlink, respectively.

First, it should be noted that there's nothing that says that future spectrum allocations for frequency division duplex must allocate the same amount of downlink spectrum as uplink spectrum. Thus, clearly systems based on frequency division duplex can support very asymmetric capacity.

However, once the spectrum allocation has been done it is difficult to adjust the ratio between uplink and downlink capacity. Thus the support for the asymmetric capacity is not very flexible in a system based on frequency division duplex.

On the other hand, for systems based on time division duplex, the uplink and downlink capacity can be adjusted by allocating a different number of timeslots for uplink and downlink, respectively.

This is illustrated in this figure, where we can see how the capacity ratio between uplink and downlink can be changed by simply changing the allocation of timeslots for uplink and downlink.

At least in theory such allocations can be changed dynamically and the relation between uplink and downlink capacity can thus be changed dynamically, depending on what is required.

TDD – Support for assymetric traffic

However, as we have mentioned, to avoid severe interference in a wireless system based on time division duplex, the same timeslots must be used for uplink and downlink transmission in neighbor cells, and probably also between neighbor bands.

Otherwise direct terminal to terminal, direct base station to base station interference may occur. Thus the possibility to change the uplink, downlink slot allocation in a dynamic way is rather limited, as this needs to be coordinated between cells, and perhaps also between neighbor operators in neighbor frequency bands.

Thus ultimately systems based on time division duplex there are substantial limitations in the support for asymmetric traffic.

TD-SCDMA

As we have already mentioned several times, 3GPP is also specifying second TDD based technology. This technology goes under the name TD-SCDMA, or time division synchronous code division multiple access.

TD-SCDMA – Background

As we have already mentioned, the TD-CDMA transmission technology was originally developed in China. However, in order to make TD-CDMA--TD-SCDMA into a global standard it was introduced into 3GPP as a second TDD mode.
It was then partly harmonized with the already existing UTRA TDD mode that is TD-CDMA. However, some key parameters, such as the chip rate, remain different between TD-CDMA and TD-SCDMA.

Thus, these two TDD modes also go under the name high chip rate TDD and low chip rate TDD, where TD-CDMA corresponds to high chip rate TDD and TD-SCDMA corresponds to low chip rate TDD.

TD-SCDMA – Key air-interface characteristics

This slide shows the most basic characteristics of the TD-SCDMA radio access technology. As can be seen, TD-SCDMA is conceptually similar to TD-CDMA.

Both technologies are based on time division duplex that is the same frequency band, but different timeslots are used for uplink and downlink transmission.
Furthermore, both technologies are based on a combination of time division multiple access and code division multiple access.

However, the chip rate, and thus also the transmission bandwidths of TD-SCDMA is only one third of the chip rate bandwidths of TD-CDMA. This is of course the reason why TD-SCDMA goes under the name low chip rate TDD, and TD-CDMA goes under the name high chip rate TDD.

There are also some other important differences between the two transmission technologies.

Synchronous CDMA

As already mentioned, TD-SCDMA stands for time division synchronous code division multiple access. The word synchronous comes from the fact that in contrast to TD-CDMA, and also in contrast to wideband CDMA, TD-SCDMA is based on synchronous uplink transmission.

We have already mentioned that in wideband CDMA, uplink transmissions are not synchronized between different users in a cell. This is the reason why non orthogonal codes are used for the wideband CDMA uplink. The same is true also for TD-CDMA.
However, for TD-SCDMA one is actually trying to achieve uplink synchronization and thus uplink orthogonality between different uplink transmissions in the same cell.

This is achieved by having the base station continuously measuring the disalignment between different uplink transmission.

Based on these measurements, the base station transmits timing control commands to the different mobile terminals. The mobile terminals are adjusted transmit timings based on these timing control commands with a step size of one eighth of a chip.

Note that in some sense this procedure is somewhat similar to uplink power control in, for example, wideband CDMA.

In case of power control, the receiver measures the deviation of the received power from a reference power level and transmits a power control command that adjusts the transmit power.
In case of timing control the receiver measures the deviation of the received timing and transmits a timing control command that adjusts the transmitter timing.

If uplink synchronization is thus uplink orthogonality can be achieved, the result is obviously reduced uplink interference and potentially improved uplink capacity. Also, the need for uplink multiuse detection can be reduced for TD-SCDMA, compared to TD-CDMA.

However, there are also some problems associated with uplink synchronous transmission. As already mentioned, uplink orthogonality implies that orthogonal codes are needed for the uplink.

As there are only a limited number of orthogonal codes, there is an obvious risk that capacity will be code limited, rather than interference limited.

Furthermore, similar to the downlink on wideband CDMA and the uplink orthogonality is at least partly lost in case of a time dispersive radio channel.

Finally, the use of orthogonal codes on the uplink implies that explicit code allocations is needed for the uplink. This obviously implies additional signaling requirements.

TD-CDMA vs TD-SCDMA

As mentioned, TD-CDMA and TD-SCDMA are quite similar from a conceptual point of view, including the same duplex scheme and the same multiple access scheme.

However, there are some key differences. We have already mentioned the difference in transmission band, with TD-SCDMA is substantially more narrow band compared to TD-CDMA. There is also a difference in the basic frame structure between the two technologies.

TD-CDMA and TD-SCDMA – Frame structure

As we've already seen TD-CDMA is based on ten millisecond frames with 15 timeslots per frame. Each timeslot can be used for either downlink or uplink transmission.

As can be seen in this figure, TD-SCDMA uses a somewhat different frame structure. This is a relatively important difference that has an impact on the possibility for coexistence of TD-CDMA and TD-SCDMA based systems in neighbor spectrum.

As we have mentioned before, there can be relatively severe interference situations in a TDD system or between different TDD systems operating in neighbor bands.

Such interference can be avoided by means of tight synchronous that is an alignment in a transmission between cells and between operators in neighbor bands.

However, it is obvious from the different frame structures of TD-CDMA and TD-SCDMA that such alignment is not really possible between the two systems. In essence, with a different frame structure it is obviously impossible to fully align uplink and downlink transmission between the two systems. Thus it may be difficult to deploy TD-CDMA and TD-SCDMA systems in neighbor bands.

3GPP Wireless Technologies Higher-Layer Protocols

Until we have completely focused on the physical layer of the 3GPP wireless technologies. However, although the physical layer characteristics are often used to characterize the wireless technology, the design and structure of the higher layer protocols is, in many cases, as important and sometimes even more important in terms of impact on the behavior, capabilities, and performance of a certain wireless technology.

In this tutorial we will not go into any details of the 3GPP higher layer protocol structure. However, we will try to give a brief overview of the protocol stack, and try to summarize what is actually done by the different protocol layers.

3GPP Protocol Architecture

This slide illustrates the overall structure of the 3GPP protocol stack. Above Layer 1 or the physical layer we have the medium access control, or MAC sublayer.

The MAC sublayer is the lower part of Layer 2. The upper part of Layer 2 consists of the radio link control, or RLC sublayer.

When it comes to Layer 3 in the control plane only the radio resource control, or RRC, is actually part of the radio access network.

Other parts of the Layer 3 control plane, such as mobility management and call control is not part of the radio access network, but is instead part of the core network. We have therefore not included these parts of Layer 3 in this figure.

In the user plane the entire Layer 3 actually lies above the radio access network. That is, the RNC is the highest layer of the radio access network protocol stack in the user plane.
For the figure we can also see how each layer provides services in terms of channels to the layer above. Thus, as can be seen, the services provided by the physical layer to the MAC layer are referred to transfer channels.

Similarly, the services offered by the MAC layer to the layer above, that is the RNC layer, are referred to as logical channels.

Finally the services offered by the RNC layer are in the user plane referred to as radio bearers. As RNC is the highest layer in the radio access network user plane, radio bearers are then obviously also the user plane services being provided by the radio access network to the core network.

Information Flow

This slide illustrates how information propagated downwards in the protocol stack before transmission over the radio channel.

At the opposite side of the radio link they receive they information, then propagates upwards through the corresponding or peer protocol stack.
More specifically, user data or user traffic is received by the RNC layer on the radio bearers. The RNC maps this data to logical channels that are fed down to the MAC layer.

The MAC layer then maps the logical channel data to transfer channels that are fed further down to the physical layer. The physical layer then takes care of the actual transmission over the radio channel.

On the opposite side of the radio link the physical layer extract the transfer channel for the physical channels. In the next step the logical channels are extracted from the transfer channels by the MAC layer.

Finally, the radio bearers are extracted from the logical channels by the RNC layer, that then sends the received information further up, out of the radio access network.

As can be seen, at the transmitter reside, each layer attaches additional information to the data. This information, or protocol heather is then extracted and used at the corresponding or peer layer at the receiver side.

Control signaling is generated internally in the radio access network in the RNC entity is communicated with the corresponding or peer RNC entity at the other side of the connection in a very similar way as user data.

In the control plane, so-called signaling bearers corresponding to the user plane radio bearers.

We will now briefly go through the different parts of the higher layer protocols in order to describe, in somewhat more detail, the functions and responsibilities of each layer.

Functions of MAC* (Medium Access Control)

This slide lists the main functions and responsibilities of the MAC, or medium access control sublayer. The main responsibility of MAC is to carry out dynamic scheduling between different users, and also between different flows of the same user.

As part of this, MAC also controls the multiplexing of different flows. Thus, the MAC controls the dynamic access to transmission medium, in this case the radio channel.
In addition to dynamic scheduling, MAC is also responsible for the dynamic rate selection, or transfer format selection.

In the end this means that MAC may dynamically adjust the data rate of each transfer channel within the limits set up by the radio resource control.

Finally, MAC also controls the dynamic selection between channel types. For example, if data is to be transmitted over a dedicated transfer channel that is a dedicated physical resource, or over a common transfer channel.

The 3GPP MAC is, as much as possible, the same for the different UTRA modes. However, as MAC is responsible for the dynamic access to the radio medium, and the radio medium obviously has somewhat different structure for UTRA FDD, that is wideband CDMA and UTRA TDD, there are obviously some differences in the MAC between the different UTRA modes.

It should also be pointed out that for wideband CDMA release 5, some new, important MAC functions have been introduced as part of the introduction of so-called high speed downlink packet access, or HSDPA. This will be described later on as part of the overview of the 3G evolution.

Functions of RLC (Radio Link Control)

The main function of radio link control, or RLC, is to turn the in general unreliable radio link into a reliable communication link, as seen by the layers above RLC.

The main function of RLC is there to carry out functions such as error correction by means of retransmissions, activities to ensure in sequence delivery of data delivered to the higher layers, and activities to avoid duplication of data delivered to higher layers and flow control. Furthermore, as can be seen, radio network level ciphering is also responsibility of RLC. Finally, it should be noted that the 3GPP RLC layer, which is relatively radio independent, is actually identical for the different UTRA modes.

Functions of RRC (Radio Resource Control)

Finally we have the RRC, or radio resource control function. The radio resource control is the entity that really owns and thus, in the end, controls the different radio resources of the radio access network, such as spreading codes, timeslots, transmit power, et cetera.

The radio resource control then assigns these two different radio links. The RLC is thus, in many ways, the true brain or the boss of the radio access network.

This means that RLC decides such things as cell selection and reselection handover, that these mobile terminals handover, and to what cell that handover should be done, and the setting of the SIR target, or SIR threshold for the power control.

The RLC also carries out the fundamental tasks of admission control. That is, to decide whether or not a new user is to be admitted into the system, as well as congestion control that is the possible dropping of a user if the system is getting congested.

It should be noted that the reasons management carried out by RLC is done on the multi cell level, that is the RLC takes into account the situation in the entire network when allocating radio resources. In this way the overall system performance can be optimized.

Similar to MAC, the RLC layer is similar but not identical for the different UTRA modes. The reason is, of course, that also the RLC layer to some extent depends on the exact structure of the radio resource that are obviously different for the different UTRA modes.

3GPP Radio-Network (RAN) Architecture

Another aspect of the radio access network is the radio access network architecture, that is the different nodes that can exist in a network and how they connect and communicate with each other.

This figure illustrates the 3GPP radio access network, or RAN architecture. In essence, the RAN architecture consists of three different types of notes.
First we have the user equipment or UE. In practice the UE is just a different name for a mobile terminal.

Second we have the Node B that corresponds to what one would typically call a base station.
Finally we have the RNC, or radio network controller. The RNC connects and control multiple node base, and also provides the link up to the core network.

The main part of the 3GPP RAN specification is actually the specifications of the different interfaces that connect to different modes.

The most obvious interface is the so-called UU interface between the UE and the Node E. This is what we in normal cases would call the error interface. However, 3GPP also specifies as to interfaces between the other RAN nodes. Thus, the interface between the Node B and the RLC, that is to specification how RLCs communicate when Node B is referred to as the IUB interface.

Similarly the interface between the RLCs and out into the core network is referred to as the IU interface.

Finally we have the IUR interface that connects different RLCs. This interface that is the possibility for different RLCs to communicate directly with each other is needed to support a, for example, soft turnover between two different node Bs that are connected to different RLCs.

UTRAN higher layers – Location in RAN

This slide illustrates the location of the radio protocol entities within the 3GPP radio network architecture. As can be seen on the network side, the main part of the radio protocol stack is actually located in the RLC, not in the Node B.

This is true for the radio resource control, for the radio link control, and for the medium access control. There are several reasons for locating these in the RLC.

As an example, by locating the radio resource control in the RLC and not in a Node B, one allows for multicell radio resource management. That is radio resource management that does not only take the situation in a single cell into account. This then allows for more optimized radio resource management.

As another example, locating the RLC and RNC simplifies handover between Node Bs. If the RLC was located in the Node B, the state of the RLC had related, for example, to the retransmission protocol would have to be moved every time a terminal made a handover to a new Node B.

On the other hand, the main part of the physical layer is for obvious reasons located in the Node B. However, some parts of the physical layer are actually also located in the RLC.

For example, uplink soft turnover combining, which is a physical layer function, obviously needs to reside in the RLC. This can also be seen from a previous slide when we discussed the soft turnover.

It should be pointed out though that for HSDPA that is part of the 3G evolution, some part of the MAC is actually also located in the Node B. As we'll see, in general HSDPA is moving functionality closer to the actual radio link.

3GPP2 Wireless Technology – cdma2000

The second major 3G technology, besides wideband CDMA, is CDMA 2000. This technology is, as we have already mentioned, currently be developed by 3GPP2.

North-American 3G spectrum situation

To understand the reasons for the CDMA 2000 3G technology we need to recapitulate once more the spectrum situation in North America.

As already mentioned, it was not possible to allocate spectrum exclusively for 3G wireless communication in North America. Instead, new 3G technologies may have to coexist with all of the deployed second generation PCS systems.

Background

In the mid-1990s the so-called IS-95 standard, also sometimes referred to as cdmaOne, also developed TIA, primarily with contributions from the Company Qualcomm.
As all other second generation technologies, IS-95 was designed for speech and low medium rate mobile data communication.

The CDMA based IS-95 standard soon became one of the major second generation technologies in North America. As already mentioned, there was no dedicated 3G spectrum in North America. Instead, PCS spectrum must be reused for 3G system.

As a consequence it was felt that there was a need for a 3G technology that could more smoothly coexist with PCS systems, especially systems based on the IS-95 standard.
This was the reason for the evolution of IS-95 into third generation technology, referred to as CDMA 2000.

Work on CDMA 2000 was initially carried out within TIA in North America. However, as the target was that CDMA 2000 should also become a global 3G test standard, similar to wideband CDMA, the global organization 3GPP2 was created to continue the work on defining CDMA 2000.

cdma2000 – Key air-interface characteristics

This slide shows the most basic characteristics of the CDMA 2000 radio access technology. As can be seen, CDMA 2000 is conceptually similar to wideband CDMA.

Both technologies use direct sequence spreading, both technologies are based on frequency division duplex, both technologies are based on the same kind of code division multiple access.

However, as can be seen, the chip rate, and that's also the transmission band is of CDMA 2000 is approximately one third, compared to wideband CDMA.

Actually the chip rate of CDMA 2000 is identical to the chip rate of IS-95. This is one of the key reasons for the possibility of smooth coexistence between CDMA 2000 and IS-95. In essence it allows for systems based on IS-95 and systems based on CDMA 2000 to coexist in the same spectrum, on top of each other.

cdma2000 physical layer – Basic principles

Also if one looks further into the details, CDMA 2000 is conceptually very similar to wideband CDMA. In addition to the same duplex and multiple access scheme, the two 3G technologies use more or less the same type of spreading codes for both downlink and uplink.
They also use similar channel coding schemes. Furthermore, similar to wideband CDMA, CDMA 2000 also uses fast power control, soft turnover, and transmit diversity. The list could actually be made even longer. Thus one can rightfully expect that wideband CDMA and CDMA 2000 should behave quite similarly in most cases.

Cdma2000/WCDMA – Key air-interface differences

However, there are some key differences between CDMA 2000 and wideband CDMA. These are differences that, to some extent, impact the relative performance and also the deployment of the two technologies.

First, wideband CDMA has, as already mentioned, a chip rate and thus a transmission bandwidth that is substantially larger than that of CDMA 2000.

Second, CDMA 2000 requires that all cells or base station are tightly synchronized to each other. In practice this means that all base stations must use a common timing reference. This is not required for C-, wideband CDMA.

Cdma2000/WCDMA – Inter-cell synchronization

So why does CDMA 2000 require tight synchronization between the cells, and what does it actually mean? As mentioned, tightening the cell synchronization means that all base stations in a system use a common timing reference. In all practical cases this common timing reference is achieved by having all base stations receive signals from the global position system, GPS.

Due to this common timing reference, the transmissions on neighboring cells can have very well defined timing rel-, offsets, relative to each other. The benefit of this is that it reduces the effort needed by the mobile terminal to find new cells, both when the terminal is powering up and when it is searching for new cells to hand over to.

This requirement for tight inter-cell synchronization was included in IS-95 as, at that time, it was seen as important to reduce the mobile terminal complexity as much as possible.

When IS-95 was later evolved into CDMA 2000 it was very natural to keep the same requirement for CDMA 2000.

The drawback of requiring tight inter-cell synchronization is that, at least in practice, all base stations must be able to receive a GPS signal. Although this is, in many cases, straightforward, to may be complicated. For example, in the case of indoor base stations.

Thus a requirement on tight inter-cell synchronization puts restrictions and complicates deployments in some cases.

For this reason, wideband CDMA was designed so that tight inter-cell synchronization should not be required. The drawback of this is of course that it makes cell search somewhat more complex. However, today this is much more of a minor issue compared to the time when IS-95 was initially deployed.

In essence one can say that the initial complexity of having to support asynchronous operation is negligible compared to overall mobile terminal complexity.

Cdma2000/WCDMA – Transmission bandwidth

The second key difference between wideband CDMA and CDMA 2000 is that wideband CDMA has an approximately three times larger transmission bandwidth.

Note here that all the wideband CDMA offer center transmission bandwidth of 5 megahertz the wideband CDMA 3 dB bandwidth, which better corresponds to the 1.25 megahertz bandwidth typically stated for CDMA 2000 is actually slightly less than 4 megahertz.
This difference in transmission bandwidth has no substantial impact on the wideband CDMA and CDMA 2000 capacity for low rate services, such as voice.

Due to the wider bandwidth, wideband CDMA can of course have many more voice uses per carrier. However, at the same time, CDMA 2000 can obviously have more carriers in a total given spectrum allocation.

So in the end the number of uses that can be supported in a cell given a certain total spectrum allocation is very similar between the two systems.
However, the difference in transmission batteries implies, rather naturally, that wideband CDMA can support higher data rates more efficiently than CDMA 2000. Too high data it simply imply a too low spreading factor or too low processing gain for CDMA 2000.
On the other hand, there are also, as we see later, some benefits of a smaller transmission bandwidth. In essence it allows for a more flexibility in the deployment of the system in different spectrum allocations.

Cdma2000/WCDMA – Voice capacity

This slide just illustrates that the voice capacity of wideband CDMA and CDMA 2000 is very similar. This is expected as voice is a typical low rate service. Once again wideband CDMA can have many more voice uses per carrier. However, this is compensated for by the fact that CDMA 2000 can have more carriers in a given total spectrum allocation.

Cdma2000/WCDMA – Data capacity (example)

On the other hand, this slide illustrates that the larger bandwidth of wideband CDMA is clearly beneficial in terms of supporting higher data rates. The figure basically shows that the--shows the data capacity as a function of the data rate, as can be seen. For low data rates, that is to the left in the figure, the wideband CDMA and CDMA 2000 capacity is, as expected, very similar. However, for higher data rates that is to the right in the figure, the wideband CDMA capacity is, also as expected, much better.

cdma2000 / WCDMA – Deployment in different spectrum

However, a more narrow bandwidth can also be beneficial in some cases. Take as an example a five megahertz spectrum allocation. In such a spectrum allocation one can fit at most one wideband CDMA carrier or at most three CDMA 2000 carriers in order to fulfill the outer band emission requirements.

If the operator instead has a ten megahertz spectrum allocation he can deploy two wideband CDMA carriers. However, it turns out that in such a spectrum allocation one can actually have seven CDMA 2000 carriers and still fulfill the outer band emission requirements.

Similarly, in a 15 megahertz spectrum allocation one can have 3 wideband CDMA, but up to 11 CDMA 2000 carriers. There is thus a slight gain in CDMA 2000 capacity relative to wideband CDMA, as one goes to larger spectrum allocations.

Note that this does not necessarily imply that CDMA 2000 has superior capacity in 10 megahertz and 15 megahertz spectrum allocations compared to wideband CDMA. It just says that the relative capacity of CDMA 2000 is improved as one goes to larger spectrum allocations.

Actually if one carries out the more detailed analysis, it turns out that for speech, CDMA 2000, wideband CDMA has very similar capacity at ten megahertz spectrum allocation. What this figure then would say is basically that for a 5 megahertz spectrum allocation, wideband CDMA has a benefit, while for a 15 megahertz spectrum allocation, CDMA 2000 may have some minor benefits.

It should also be noted this figure is used and all carriers are deployed in the same cell layer. If the carriers are deployed in different cell layers, for example, some carriers in the micro layer and some carriers in an overlaid macro layer, a larger carrier spacing will be needed between the carriers in the different layers.

It will then typically not be possible to deploy, for example, seven CDMA 2000 carriers in a ten megahertz spectrum allocation.

The evolution of 3G Wireless Technologies

In this last part of the tutorial we will discuss some parts of the evolution of the 3G wireless technologies.

As we have already mentioned, this revolution has already begun, and is a revolution that will clearly continue also in the future.

Why 3G evolution?

First we can ask ourselves why is this evolution taking place, and especially why is it taking place already now?

There are actually at least three reasons for evolving the 3G wireless technologies.
First there is a constant evolution or refinement of both operators and end users are expected from mobile communication systems.

For example, due to the emergence of new types of applications and services, and it is important that the 3G wireless technologies are continuously evolving in order to satisfy these changing requirements.

Second, basic technology, such as processing power, what can be implemented on a given chip size with a reasonable power consumption, et cetera, et cetera, is continuously advancing, and the 3G wireless technologies should then evolve in order to take advantage of these technology advances.

Finally there is undoubtedly continuous competition between different wireless technologies. Both between different 3G wireless technologies, such as wideband CDMA versus CDMA 2000, but also between the 3G technologies and other alternative wireless technologies, such as, for example, wireless LAN technologies.

A continuous evolution of the 3G wireless technologies is therefore needed, simply to ensure that these technologies stay competitive to the other wireless technologies.
So what are then the fundamental targets of the 3G evolution? Well, in principle one can say that the targets are twofold. The first is improved performance, typically in terms of system capacity and coverage. That is simply the possibility for an operator to be able to serve more users over a larger area with fewer cell size. That is, in essence, less infrastructure investment.

And second, improved service provision that is the possibility for the operator to offer to the end user new or improved services. For example, high data rates or reduced delay. Typically the kind of service that is then being targeted is packet data services. That is in essence allowing for web browsing, file downloading, et cetera, with high data rates and/or reduced delay.

Evolution of the 3G Wireless Technologies

As we can see on this slide, the evolution of wideband CDMA is actually relatively straightforward. In the first step of the wideband CDMA, means for improved downlink packet access was introduced as part of wideband CDMA release 5 in 2002.

In the second step additional means for improved uplink packet access was introduced as part of wideband CDMA release 6 in 2004.

For CDMA 2000 the evolution has, technology wise, been very similar to that of wideband CDMA. With first introduction improved downlink or forward link packet access, followed by improved uplink, or reverse link packet access.

However, the situation for CDMA 2000 is somewhat complicated by the fact that for the CDMA 2000 evolution there are actually two different evolution tracks, known as 1X EV-DV and 1X EV-DO, respectively. We will later describe this in somewhat more detail.

However, the important thing is that from a technology point of view the enhancements introduced in HSDPA and those introduced for CDMA 2000 as part of 1X EV-DV and 1X EV-DO are quite similar. Thus we will describe these techniques mainly in the context of wideband CDMA. But it's then important to have in mind that similar techniques are applied also to the CDMA 2000 evolution.

Enhanced downlink (forward link) packet access

We will start with an overview of the techniques introduced to improve the downlink packet access of wideband CDMA and CDMA 2000. In the case of wideband CDMA, that is in 3GPP, these enhancements go under the name HSDPA, or high speed downlink packet access.

In 3GPP2 the corresponding enhancements are part of CDMA 2000 revision C or 1X EV-DV and the so-called 1X EV-DO revision zero.

Enhanced downlink packet access – Key techniques

This slide shows the key techniques that have been introduced in both 3GPP and 3GPP2 in order to enhance a support for downlink packet data transmission for wideband CDMA and CDMA 2000.

First, the key characteristics is that enhanced downlink packet access is based on so-called shared channel transmission. In short this means that not only the base station power, but also the downlink code resource is seen as a shared resource that is dynamically shared between different users.

In order to reduce the delay, and also to enable several of the other key techniques, the frame lengths, or in 3GPP terminology, the transmission time interval, or TTI, is reduced as part of the enhanced downlink.

For HSDPA that is for the wideband CDMA enhanced downlink. The minimum TTI is reduced from 10 millisecond in the first release of the wideband CDMA to 2 milliseconds for HSDPA.

The evolution of both wideband CDMA and CDMA 2000 includes the introduction of higher order modulation for the downlink. More specifically, 16 qa modulation and in the case of CDMA 2000, also 8 psk modulation has been introduced as a complement to the Q/psk modulation supported in the first releases of the wideband CDMA and CDMA 2000 standards.

The main reason for introducing support for higher-order modulation is to allow for high data rates within a given transmission bandwidth.

However, as we'll see later, the possibility to use higher-order modulation also allows for higher efficiency. In essence, higher system capacity in case of good channel conditions. A key technique, or rather to keep two key techniques used to enhance the performance of downlink packet data is the utilization of so-called fast scheduling and fast rate control.

In short, this means that the selection of what's used to transmit to and with what rate to use for transmission of that user depends on the instantaneous channel conditions of each user. The final technique introduced as part of the downlink enhancements is fast ARQ with soft combining. This basically means two things. First, that transmissions, in case of errors, are done very quickly, or retransmissions in case of errors are done very quickly in order to minimize the delay. And that so-called soft combining is applied at the receiver in order to utilize all received energy. Also energy from failed transmissions.

We will now describe these different techniques in more detail. We will do this description with focus on HSDPA, that is the wideband CDMA evolution towards enhanced downlink package access.

However, we should then have in mind that very similar techniques are used also for the CDMA 2000 evolution.

Shared-Channel Transmission

First we note that in CDMA based wireless systems, such as wideband CDMA and CDMA 2000, there are two basic downlink radio resources. First the code resource, that is a set of orthogonal codes on the downlink. And second, the available base station transmit power. In both wideband CDMA and CDMA 2000 the available base station power is typically dynamically allocated to different users by means of power control.
However, the code resource is typically semi-statically allocated. This simply means that a user is allocated a code of a certain spreading factor. This code is then used for transmission to this user for a relatively long time duration.

This can also be referred to as dedicated channel transmission, as the code or the channel is dedicated to a certain user for a certain time.

However, for the enhanced downlink packet access, both the code resource and the power is dynamically allocated to users, primarily by means of time multiplexing.
This is what we refer to as shared channel transmission, as all resources, both power and codes, are dynamically shared between the users.

Shared-channel transmission – Code resource (HSDPA)

In case of HSDPA, that is the wideband CDMA evolution towards enhanced downlink packet access, the shared code resource consists of a number of codes of constant spreading factor of 16. This can be seen in this figure. How many codes that are part of this shared code resource depend on how many codes are needed for other types of transmissions.

In the extreme case, up to 15 codes, that is more than 90 percent of the downlink code resource, can be used for HSDPA transmission. Obviously this implies that the channel can carry very high data rates.

In this specific figure we have assumed that the HSDPA code resource consists of 12 codes of spreading factor 16, that is 75 percent of the overall code resource.

Shared-channel transmission – Code allocation

This slide illustrates the dynamic sharing of codes in HSDPA. We can see that for each transmission time interval, or TTI, which for HSDPA is two milliseconds, as mentioned, the entire HSDPA code resource can be used for transmission to a single user. Thus HSDPA allows for very high instantaneous data rates to a single user.

Furthermore, as we'll see later, by being able to allocate the entire HSDPA code resource to a single user, one can use the entire code resource that is a large part of the overall cell capacity for transmission to a user with instantaneously very good radio channel conditions. This is what we refer to as channel dependent, or fast scheduling. This allows for more efficient utilization of the code resource, and thus leads to higher overall system efficiency. However, as can be seen in this figure, there is also a possibility to split the code resource and transmit data to multiple users in parallel, using different subsets of the shared code resource.

There are two reasons why there is a possibility for this kind of code multiplexing. First, all mobile terminals may, simply due to implementation constraints, not be able to receive all HSDPA codes.

For example, at some terminals may only be able to receive a maximum of five codes, and some other terminals may only be able to receive a maximum of ten codes, and it is then obvious that if the HSDPA code resource consists of, for example 12 codes, there is a need to code multiplex several users within the HSDPA code resource.
A second reason why code multiplexing is needed is simply that there may sometimes not be sufficient data available for a certain user to fill all the HSDPA codes.

Anyway, the key thing illustrated in this slide is that in case of HSDPA transmission, the code resource can be dynamically allocated to users on a two millisecond TTI basis. This is much faster than what is possible for the first release of wideband CDMA, and this is what justifies the term shared channel transmission, that is the code resource is dynamically shared between the different users.

Shared-channel transmission – Power allocation

This slide illustrates the dynamic sharing of a base station power allocation of HSDPA. In general the base station power consists of three parts.

First we have the constant traffic power needed for common channels, such as pilot channel, road cross channels, et cetera.

Second we have the transmit power needed for dedicated channels such as voice and other types of channels. As these channels are power controlled the corresponding required transmit power obviously varies in time, as you can also see from this figure.

Finally we have the remaining base station power that can be used for shared channel transmission. Note that the power available for the shared channel transmission varies in time, depending on how much power is needed for the power controlled dedicated channels. This means that shared channel transmission allows for very efficient power utilization in the sense that all available base station power can be utilized at every moment in time.

Fast rate control

This slide illustrates the basic principles of fast rate control. Due to fading and other channel effects, the radio channel conditions, or the channel quality varies continuously. In early releases of wideband CDMA this is, as we had mentioned earlier, compensated for by means of power control.

Power control implies that the transmit power is increased when the channel conditions are bad and reduced when the channel conditions are good. This is typically something that is needed for services requiring a constant data rate, such as voice services.

However, fundamentally this is an efficient solution in the sense that most resources, that is most transmit power is used in case of bad channel conditions.

At the same time, resources are most efficiently used when they are used with channels with high quality.

For data services there is often not a requirement on constant data rates. It is therefore more efficient to use fast rate control, rather than fast power control.
Fast rate control simply means that instead of varying the power to compensate for varying radio channel conditions, which is done in case of power control, the data rate is instead varied.

In essence, when the channel conditions are improved, the data rate is increased and similarly when the channel conditions are degraded, the data rate is reduced.
In practice, these adjustments are done in steps. That is, when the channel quality goes above a certain threshold, the data rates is increased. Similarly, when the channel quality goes below the threshold, the data rates is reduced.

As illustrated in this figure, the data rate is in practice adjusted by adjusting either the modulate scheme and/or the channel coding rate.

This is the reason why the support of high order modulation, such as 16 qm can improve not only the data rates that can be supported, but also overall system efficiency.

The possibility to use higher order modulation, such as 16 qm, simply means that fast rate control can be more efficient. Without higher order modulation only the channel coding could be changed in order to vary the rate.

Very high data rates would then imply the need for very high rate channel coding that is in essence an inefficient channel coding rate.

Obviously in order to adjust the data, the base station needs some knowledge of the downlink channel quality. In HSDPA this is achieved by the mobile terminal continuously reporting the downlink channel quality to the base station. This reporting can be done as often as once every two milliseconds. That is once every TTI.

Fast channel-dependent scheduling

This slide illustrates the basic principles of fast channel dependent scheduling. Once again, due to fading and other channel effects, the channel quality will continuously vary. Obviously these variations will be different for different users.

This means that the channel quality of one user may be very good at the same time as the channel quality of another user is momentarily at least, very bad.

As we have already explained, with fast rate control the data rate depends on the instantaneous channel conditions. Thus it is obviously beneficial to transmit to a user with good channel conditions rather than to a user with bad channel conditions.

In this way the transmission rate from the base station is maximized and, as a consequence, the overall cell throughput, or the overall bit rate that goes out of the cell is maximized. Similar to fast rate control also these fast channel dependent scheduling obviously requires feedback of information about the downlink channel quality from all UEs or alternatives in the cell.

In practice the same information as for the rate control can be used also for the fast channel dependent scheduling.

Fast channel-dependent scheduling, cont

Obviously channel dependent scheduling is always a tradeoff between maximizing the overall cell throughput and some kind of fairness among the users.

In principle maximum cell throughput is achieved by always allocating the channel to the user with the best channel quality. This is also known as so-called maximum C or I scheduling because in that case we schedule the user with the maximum C or I or the maximum signal to interference ratio.

However, such a scheduling policy can obviously lead to a situation where user at the cell border never receives any data whatsoever because that user never has the best channel. And this is a problem not acceptable in most cases.

The other extreme case is to allocate resources in a round robin, or regular TDMA fashion, not taking into account the channel quality.

This basically means that we do not do any channel dependent scheduling whatsoever, and then of course cannot really benefit from the gains of channel dependent scheduling.
Thus in practice one should use a scheduling language that is somewhere between these two extreme cases. As an example, one could use a scheduling language that utilizes fast variations in the channel quality. As the corresponding fast variations in the service quality, it's probably not noticeable to the user.

However, the scheduling language should try to avoid large, long term variations and differences in the service quality. One such scheduling algorithm is known as the proportionally fair scheduler.

It should also here be noted that the HSDPA scheduling language is not something that is specified by 3GPP, but is rather specific to every base station vendor or operator.
What is specified by 3GPP is simply the uplink and downlink signaling needed to support fast channel dependent scheduling.

Fast ARQ with soft-handover

Fast ARQ with soft combining is the final key feature of HSDPA. If we consider a conventional ARQ scheme, it typically works according to the principal that the receiver decodes the received signal and checks for errors. If an error is detected, the received block is discard and a retransmission is requested.

However, even if the received block was not possible to decode correctly, it is quite obvious that it still contains some useful information. This is the basic idea between ARQ with soft combining.

Similar to normal ARQ, a received block with ARQ soft combining is decoded and checked for errors. If an error is detected, the retransmission is requested exactly as the normal ARQ. However, in contrast to normal ARQ, in the case of ARQ with soft combining, the received block is not discarded. Instead it is saved and later on combined with the retransmission.

By doing so, one in essence increases the probability for correct decoding after retransmission, as one at that stage has the information both from the original transmission and the retransmission.

There are two basic alternatives for ARQ with soft combining, often referred to as chase combining and incremental redundancy, or IR.

In case of chase combining, each retransmission is identical to the original transmission. Each retransmission then just adds more energy.

On the other hand, in case of incremental redundancy, each retransmission consists of the same information as the original transmission. However, the original transmission may consist of a different set of coded bits. Thus, with incremental redundancy one does not only get an energy gain by soft combining, there is also the possibility for increased channel coding gain.

Principle of Fast ARQ with soft combining

This figure illustrates the principle of normal ARQ. We note that when an error occurs the receiver requests a retransmission, and when the retransmission is received, the receiver uses only retransmission as--but has discarded the previous transmission.

Principle of Fast ARQ with soft combining

In contrast, in this lower figure we illustrate the principle of ARQ with soft combining. We see how free retransmission, the different received blocks are combined before decoding, especially we note that for packet number two, soft combining implies that after one retransmission there is sufficient energy for correct decoding.

In contrast for the normal or conventional ARQ, three transmissions are needed for the packet number two, as we can see in the upper figure.

cdma2000 evolution – Enhanced forward link

As already mentioned, the evolution of CDMA 2000 consists of two different paths; CDMA 2000 1X EV-DV and CDMA 2000 1X EV-DO, or just 1X EV-DO.

For both these parts there is a similar evolution as for HSDPA, that is the introduction of shorter frames, the introduction of high order modulation, the introduction of fast channel dependent scheduling and fast rate control, and the introduction of fast retransmissions with soft combining.

cdma2000 evolution – 1xEV/DV vs 1xEV/DO

So why are there two evolution tracks of CDMA 2000? Or rather first why the term 1X? Well, the reason for the term 1X is simply that CDMA 2000 is, or at least used to be, sometimes referred to as CDMA 2000 1X. And the reason for this was simply that very early in the development of CDMA 2000 there was actually also a five band version of CDMA 2000 with a chip rate three times that of IS-95.

The mode was then labeled CDMA 2000 3X, while the more narrow band mode was labeled 1X.

Eventually the wider band mode disappeared, partly due to the emergence of wideband CDMA. However, the 1X label remained for CDMA 2000.

1X EV-DV stands for 1X evolution, data and voice, and is a very direct evolution or extension of CDMA 2000 for improved packet data support.

This direct evolution also implies that 1X EV-DV allows for enhanced packet data access, and original CDMA 2000 services including voice on the same carrier. This is of course then the reason for the name data and voice, or DV.

In this sense, 1X EV-DV is very similar evolution or extension of CDMA 2000 as HSDPA is an evolution or extension of wideband CDMA. In the sense that also for wideband CDMA and HSDPA one can mix packet data services and other services, such as voice, on the same carrier.

1X EV-DO instead stands for 1X evolution, data only. In contrast to 1X EV-DV, 1X EV-DO is a packet optimize complement to CDMA 2000, rather than an extension. This means that 1X EV-DO in itself does not include CDMA 2000 as a subset. Rather, if an operator is to offer, for example, packet data and voice services, he has to do this using two carriers; one carrier for packet data using 1X EV-DO, and a separate carrier for voice using CDMA 2000.

The only commonality between CDMA 2000 and 1X EV-DO is actually an Rf compatibility. That is, CDMA 2000 and 1X EV-DO has the same spectrum properties.

An operator that wants to provide improved downlink packet access can therefore replace the single CDMA 2000 carrier with a 1X EV-DO carrier.

Enhanced uplink (reverse link) packet access

In the second step of the 3G evolution, new features are added to enhance all the uplink packet access. In 3GPP this evolution step is referred to as enhanced uplink. The corresponding step, or rather steps in 3GPP2 are referred to as CDMA 2000 revision D or 1X EV-DV revision D and 1X EV-DO revision A.

Why enhanced uplink/reverse-link?

So why is there a need for enhanced uplink packet access? Well, to some extent one can say that it is the enhancements to the downlink packet access that is HSDPA provide than CDMA, and the corresponding evolution or rather evolutions of CDMA 2000 that lead to a potential need to enhance all the uplink packet access.

With the enhancements such as HSDPA the capacity, as well as the delay of the downlink, has been significantly improved. Thus there is a risk that actually the uplink may be a future bottleneck. This is especially the case in terms of delay.

The important delay in almost all cases is the roundtrip time. That is the time from mobile station up to the network and back again to the mobile station.

HSDPA obviously addresses only half of this. That is in the downlink delay. Thus, in order to substantially reduce the overall round trip delay, it is important to also reduce the uplink air interface delay.

In general the target for the uplink enhancements are also for the uplink, both improved performance and improved service provision. Or more exactly, improved uplink capacity, reduced uplink air interface delay, and improved coverage for high data rates.

Enhanced uplink packet access – Key techniques

This slide illustrates the key techniques introduced to enhance the uplink packet access of wideband CDMA.

The introduction of shorter TTI on fast retransmissions with soft combining is, in principle, very similar to HSDPA that is for the downlink enhancements.
A shorter TTI is reduced in order to reduce the delay and also enable other key techniques, such as fast retransmissions and possibility for fast scheduling.

Fast retransmission with soft combining also reduces the delay due to the faster retransmissions. It also allows for higher efficiency, similar to the downlink, not only the retransmissions, but also the previously received transmissions are used in the decoding process.

It should be noted that for the uplink, the soft combining takes place in the base station or in the Node B. This imposes some specific issues compared to the downlink when the uplink is in soft turnover. That is when the uplink transmission is received at two different Node Bs.
The final key feature of the enhanced uplink packet access is the introduction of fast scheduling and fast rate control. Although fast scheduling and fast rate control is used also for the downlink as part of HSDPA, the role of fast rate control and fast scheduling is actually quite different for the uplink as we will see.

Uplink scheduling

For the downlink the shared resource is the base station transmit power and the code resource.

In contrast, for the non orthogonal interference limited uplink, as the uplink of wideband CDMA or the uplink of CDMA 2000, the shared resource is the interference level at the base station.

A key property of this resource is that it is utilized by the mobile terminals to their uplink transmissions. However, the instantaneous utilization of this resource is only known at the receiver. That is, at the base station. This makes uplink scheduling a more complicated problem compared to the downlink by both the knowledge and the control of the resources. It is at the base station.

The fundamental target of the uplink scheduling is to first ensure that the uplink resource, that is the allowable interference level is well utilized, but at the same time, not over utilized, as that would imply a too high interference level that is in essence no uplink signal could be properly detected.

At the same time, the uplink scheduling should allow for UEs or terminals to get fast access to uplink resources in order to reduce the delay. And the uplink scheduling should also allow for very data rates from single user terminal if the situations will allow. That is, if no other user needs access to the uplink at the same time.

Uplink scheduling

To achieve this, the uplink scheduling basically allows for two different transmission methods, or means for transmission.

First the so-called node B control, or centralized scheduling. This basically means that the node B, by means of fast downlink signaling, determines what user or users are allowed to transmit on the uplink on a given TTI. And also with what data rate they're allowed to transmit. That is in essence with what interference they are allowed to cause.

This scheduling can be done in a TTI basis. That is, on a two millisecond basis that is relatively rapidly. And in this way the node B can have tight control over the interference level and ensure that the allowed interference level is well utilized, and at the same time it's not exceeded.

At the same time, users can access the network without being explicitly scheduled. However, in that case they are only allowed to transmit with a certain maximum data rate.
In this way a user can get very fast cases to the uplink, especially at low load situations.

3G evolution – overall benefits

So what are the benefits of the 3G evolution? In essence one can say that the 3G evolution, until now, implies benefits in terms of capacity, in terms of capacity and enhancements in the order of two to four times for the downlink, and approximately 2 times for the uplink.

The 3G evolution also implies the availability of much higher data rates, compared to the first release of the 3G wireless technologies. Actually in theory the CDMA 2000 evolution, that is 1X EV-DO and 1X EV-DV, allows for downlink data rates up to around 3 megabits, while HSDPA allows for data rates up to 14 megabits per second.

However, these are of course some of theoretical numbers as they assume extremely good channel conditions. However, also in real life scenarios, at least HSDPA allows for really multi megabit data rates.

Finally, last but not at all least, the 3G evolution allows for significantly reduced air interface delay. This is, as we have already touched upon, important both for delay sensitive services, such as for example, interactive gaming. However, a low delay is also very important for interaction with some higher layer protocols, such as TCP.

Thank You

You have now reached the end of this tutorial on 3G wireless technologies. Thank you very much for your attention.

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Glossary

3G

Third Generation. Refers to the next generation of wireless systems - digital with high speed data. Being standardized by 3GPP and 3GPP2.

CDMA

Code Division Multiple Access. Implemented in AMPS-compatible systems by IS-95.

cdma2000

Trade name for CDMA air interface standards aimed at 3G requirements, including IS-2000. It operates in 1.25 MHz carriers at 1.2288 Mcps. There is some debate about whether the "CDMA" should be upper or lower case .

MIMO

Multiple Input, Multiple Output antennas. This increases throughput and reduces bit error rates compared to traditional antenna systems which transmit and receive through a single antenna.

UTRA

Universal Terrestrial Radio Access.

W-CDMA

Physical layer of the FDD mode of operation of UTRA. A ‘European’ version of CDMA and the 3G evolutionary step planned for GSM. Operates in pairs of 5 MHz channels at 3.84 Mcps.

Walsh codes

A group of 2N vectors or words which contain 2N binary elements which with themselves and their logical inverses form a mutually orthogonal set.

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